Claims

What is claimed is:

1. An apparatus for detecting an analyte or measuring a property of an analyte, comprising:
   a) at least one suspended beam connected to two mechanically stable supports, wherein the beam contains one or more microfluidic channels, and wherein each microfluidic channel has at least one chemical species that binds to or reacts with the analyte; and
   b) one or more detectors for measuring a change in the one or more beams upon binding or reaction of the analyte.

2. The apparatus of Claim 1, wherein the chemical species is a capture ligand that binds to the analyte.

3. The apparatus of Claim 2, wherein the one or more beams are resonating and the detector measures changes in resonance frequency of the beam.

4. The apparatus of Claim 3, wherein the capture ligand is bound to the interior surface of the microfluidic channel.

5. The apparatus of Claim 3, further comprising a gel in the microfluidic channel, wherein the capture ligand is bound to the gel.

6. The apparatus of Claim 5, wherein the beam has two microfluidic channels that meet in a region containing a polymerized gel then separate downstream from the gel.

7. The apparatus of Claim 6, wherein the analyte is transported into the gel via pressure from the fluid flow.

8. The apparatus of Claim 6, wherein the analyte is transported into the gel via electrophoresis.

9. The apparatus of Claim 3, wherein the resonance of each beam is driven by a pair of electrodes.

10. The apparatus of Claim 9, wherein one of the electrodes of the electrode pair is common to all the beams and the other electrode of the electrode pair is separately addressable for each beam.

11. The apparatus of Claim 10, wherein the electrodes are a metal that is, independently, selected from the group consisting of gold, nickel, platinum, aluminum, copper, antimony, tin, indium, chromium, titanium, and alloys thereof.

12. The apparatus of Claim 11, wherein the electrodes are gold.

13. The apparatus of Claim 10, wherein the common electrode is in contact with the each beam.

14. The apparatus of Claim 10, wherein the solution in the microfluidic channel is an electrolyte solution and the electrolyte solution is the common electrode.

15. The apparatus of Claim 3, wherein the one or more detectors are one or more capacitors.

16. The apparatus of Claim 15, wherein the drive electrodes are also used as a capacitive detectors.

17. The apparatus of Claim 16, wherein one of the two capacitor plates of each capacitive detector is in contact with the surface of the beam.

18. The apparatus of Claim 3, wherein the detector is an optical lever or a laser vibrometer.

19. The apparatus of Claim 3, wherein the capture ligand is a nucleic acid.

20. The apparatus of Claim 19, wherein the capture ligand is a single stranded DNA.

21. The apparatus of Claim 19, wherein the capture ligand is double stranded DNA.

22. The apparatus of Claim 3, wherein the capture ligand is a protein, peptide or a protein nucleic acid (PNA).

23. The apparatus of Claim 22, wherein the capture ligand is an antibody or an antibody fragment.

24. The apparatus of Claim 3, wherein the capture ligand is an antigen.

25. The apparatus of Claim 22, wherein the capture ligand is a lectin.

26. The apparatus of Claim 3, wherein the capture ligand is a carbohydrate.

27. The apparatus of Claim 26, wherein the capture ligand is a sugar residue.

28. The apparatus of Claim 2, wherein the detector measures the conductivity of the microfluidic channel.

29. The apparatus of Claim 2, wherein the detector measures deformation of the beam.

30. The apparatus of Claim 29, wherein capture ligand is bound to the interior surface of the microfluidic channel, and wherein there is a substantially higher concentration of capture ligand on one side of the microfluidic channel than on the opposite side.

31. The apparatus of Claim 29, wherein the one or more detectors are one or more capacitors.

32. The apparatus of Claim 31, wherein one of the two capacitor plates of each capacitive detector is in contact with the surface of the beam.

33. The apparatus of Claim 29, wherein the detector is an optical lever.

34. The apparatus of Claim 29, wherein the capture ligand is a nucleic acid.

35. The apparatus of Claim 34, wherein the capture ligand is a single stranded DNA.

36. The apparatus of Claim 34, wherein the capture ligand is double stranded DNA.

37. The apparatus of Claim 29, wherein the capture ligand is a protein, peptide or a protein nucleic acid (PNA).

38. The apparatus of Claim 37, wherein the capture ligand is an antibody or an antibody fragment.

39. The apparatus of Claim 29, wherein the capture ligand is an antigen.

40. The apparatus of Claim 29, wherein the capture ligand is a lectin.

41. The apparatus of Claim 40, wherein the capture ligand is a carbohydrate.

42. The apparatus of Claim 41, wherein the capture ligand is a sugar residue.

43. The apparatus of Claim 1, wherein the depth of the one or more microfluidic channels is in the range of between about 100 nm and about 3000 nm.

44. The apparatus of Claim 43, wherein the walls of the microfluidic channel have a thickness in the range of between about 100 nm and 1200 nm.

45. The apparatus of Claim 44, wherein an inlet to the microfluidic channel is connected to a sample fluid channel having a depth in the range of between about 10 μm and about 100 μm.

46. The apparatus of Claim 1, wherein the beam is suspended in a low pressure environment.

47. An apparatus for detecting an analyte or measuring a property of an analyte, comprising:

a) a device structure having at least one suspended beam that contains one or more microfluidic channels, wherein each microfluidic channel has at least one chemical species that binds to or reacts with the analyte; and

b) a sample fluid channel connected to the inlet of at least one of the microfluid channel, wherein the sample fluid channel has a depth that is substantially larger than the microfluidic channel.

48. The apparatus of Claim 47, wherein the apparatus is a micro-electro-mechanical system (MEMS) having a packaging structure that covers the device region.

49. The apparatus of Claim 48, wherein each of the microfluidic channels has a depth in the range of between about 100 nm and about 3000 nm, and each of the sample fluid channels has a depth in the range of between about 10 μm and 100 μm.

50. The apparatus of Claim 49, wherein the walls of the microfluidic channel have a thickness in the range of between about 100 nm and 1200 nm.

51. The apparatus of Claim 49, wherein the sample fluid channels are patterned in the packaging structure.

52. The apparatus of Claim 51, wherein the chemical species is a capture ligand that binds to the analyte.

53. The apparatus of Claim 52, further including one or more detectors.

54. The apparatus of Claim 53, wherein the one or more beams are resonating and the detector measures changes in resonance frequency of the beam.

55. The apparatus of Claim 54, wherein the suspended beam is a cantilever.

56. The apparatus of Claim 54, wherein the suspended beam is connected to two mechanically stable supports.

57. The apparatus of Claim 54, wherein the capture ligand is bound to the interior surface of the microfluidic channel.

58. The apparatus of Claim 54, further comprising a gel in the microfluidic channel, wherein the capture ligand is bound to the gel.

59. The apparatus of Claim 56, wherein the beam has two microfluidic channels that meet in a region containing a polymerized gel then separate downstream from the gel, wherein the gel comprises a capture ligand.

60. The apparatus of Claim 59, wherein the analyte is transported into the gel via pressure from the fluid flow.

61. The apparatus of Claim 59, wherein the analyte is transported into the gel via electrophoresis.

62. The apparatus of Claim 54, wherein the resonance of each beam is driven by a pair of electrodes.

63. The apparatus of Claim 62, wherein one of the electrodes of the electrode pair is common to all the beams and the other electrode of the electrode pair is separately addressable for each beam.

64. The apparatus of Claim 63, wherein the electrodes are a metal, independently, selected from the group consisting of gold, nickel, platinum, aluminum, copper, antimony, tin, indium, chromium, titanium, and alloys thereof.

65. The apparatus of Claim 64, wherein the electrodes are gold.

66. The apparatus of Claim 63, wherein the packaging structure comprises the separately addressable electrodes.

67. The apparatus of Claim 66, wherein the common electrode is in contact with the each beam.

68. The apparatus of Claim 66, wherein the solution in the microfluidic channel is an electrolyte solution and the electrolyte solution is the common electrode.

69. The apparatus of Claim 54, wherein the one or more detectors are one or more capacitors.

70. The apparatus of Claim 69, wherein the drive electrodes are also used as a capacitive detector.

71. The apparatus of Claim 70, wherein one of the two capacitor plates is in contact with the surface of the beam.

72. The apparatus of Claim 71, wherein the packaging structure comprises a substrate made of a material selected from the group consisting of glass, a ceramic, a plastics, a circuit board, and a silicon chip.

73. The apparatus of Claim 54, wherein the one or more detectors are optical lever detectors or laser vibrometers.

74. The apparatus of Claim 72 or 73, wherein the substrate is bound to the MEMS via a polydimethylsiloxane gasket.

75. The apparatus of Claim 74, wherein the connection between the microfluidic channels and the sample fluid channels are patterned in the polydimethylsiloxane gasket.

76. The apparatus of Claim 77, wherein the common electrode is a patterned metallic layer on the surface of the MEMS that is bound to the gasket.

77. The apparatus of Claim 72 or 73, wherein the substrate is glass or a silicon chip and is bound to the MEMS via anodic bonding.

78. The apparatus of Claim 77, wherein the connection between the microfluidic channels and the sample fluid channels are patterned in the substrate.

79. The apparatus of Claim 78, wherein the common electrode is a patterned metallic layer on the surface of the MEMS that is bound to the substrate.

80. The apparatus of Claim 72 or 73, wherein substrate is bound to the MEMS via a patterned metallic layer.

81. The apparatus of Claim 80, wherein the connection between the microfluidic channels and the sample fluid channels are patterned in the metallic layer.

82. The apparatus of Claim 53, wherein the capture ligand is a nucleic acid.

83. The apparatus of Claim 82, wherein the capture ligand is a single stranded DNA.

84. The apparatus of Claim 82, wherein the capture ligand is double stranded DNA.

85. The apparatus of Claim 53, wherein the capture ligand is a protein, peptide or a protein nucleic acid (PNA).

86. The apparatus of Claim 85, wherein the capture ligand is an antibody or an antibody fragment.

87. The apparatus of Claim 53, wherein the capture ligand is an antigen.

88. The apparatus of Claim 53, wherein the capture ligand is a lectin.

89. The apparatus of Claim 53, wherein the capture ligand is a carbohydrate.

90. The apparatus of Claim 89, wherein the capture ligand is a sugar residue.

91. The apparatus of Claim 53, wherein the detector measures deformation of the beam.

92. The apparatus of Claim 53, wherein capture ligand is bound to the interior surface of the microfluidic channel.

93. The apparatus of Claim 92, wherein there is a substantially higher concentration of capture ligand on one side of the microfluidic channel than on the opposite side.

94. The apparatus of Claim 92, wherein a surface of the beam is coated with a material having a different coefficient of thermal expansion from that of the beam.

95. The apparatus of Claim 93 or 94, wherein the one or more detectors are one or more capacitors.

96. The apparatus of Claim 95, wherein the packaging structure comprises one of the capacitor plates of each capacitor and the other capacitor plate is in contact with the surface of the suspended beam.

97. The apparatus of Claim 9, wherein the one or more detectors are optical lever detectors.

98. The apparatus of Claim 92, wherein the capture ligand is a nucleic acid.

99. The apparatus of Claim 98, wherein the capture ligand is a single stranded DNA.

100. The apparatus of Claim 98, wherein the capture ligand is double stranded DNA.

101. The apparatus of Claim 92, wherein the capture ligand is a protein or peptide.

102. The apparatus of Claim 101, wherein the capture ligand is an antibody or an antibody fragment.

103. The apparatus of Claim 92, wherein the capture ligand is an antigen.

104. The apparatus of Claim 92, wherein the capture ligand is a lectin.

105. The apparatus of Claim 92, wherein the capture ligand is a carbohydrate.

106. The apparatus of Claim 105, wherein the capture ligand is a sugar residue.

107. A semiconductor wafer comprising more than one apparatus of Claim 48.

108. A method of fabricating a functionalized microfluidic channel having an inlet and an outlet, comprising the steps of:

a) depositing a first channel layer on a semiconductor wafer having one or more trenches;

b) depositing a sacrificial layer on the first channel layer;

c) removing the sacrificial layer via planarization down to the first channel layer, thereby exposing a planar surface of the first channel layer having the sacrificial layer in the trenches;

d) depositing a second channel layer on the planar surface;

e) forming one or more holes in the second channel layer connected to one or more of the trenches;

f) removing the sacrificial layer, or a portion thereof, from the trenches by etching, thereby forming a microfluidic channel; and

g) functionalizing the interior of the microfluidic channel with a capture ligand.

109. The method of Claim 108, wherein a portion of the semiconductor wafer is removed below the microfluidic channel, thereby forming a suspended beam containing the microfluidic channel.

110. The method of Claim 109, wherein the portion of the semiconductor wafer is removed by etching the wafer from the backside below the microfluidic channel until the first channel layer is reached.

111. The method of Claim 110, wherein the portion of the backside of the semiconductor wafer is removed simultaneously with removal of the sacrificial layer from the trenches.

112. The method of Claim 108, wherein:

a) the semiconductor wafer is a silicon wafer;

b) the first and the second channel layers are silicon nitride or silicon dioxide; and

c) the sacrificial layer is polysilicon.

113. The method of Claim 112, further comprising the step of doping a section of the sacrificial layer, wherein the doped section of the sacrificial layer remains in the channel after etching.

114. The method of Claim 108, wherein the first and the second channel layers are doped polysilicon.

115. The method of Claim 108, wherein the microfluidic channel has a depth in the range of between about 100 nm and about 3000 nm.

116. The method of Claim 115, wherein the first and the second channel layers have a thickness in the range of between about 100 nm and about 1200 nm.

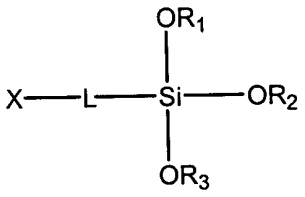
117. The method of Claim 108, wherein the step of functionalizing the interior of the microfluidic channel comprises binding a capture ligand to an inner surface of the microfluidic channel.

118. The method of Claim 112 or 114, wherein the step of functionalizing the interior of the microfluidic channel with a capture ligand, comprises the steps of:

a) contacting the surface of the microfluidic channel with a silane linker, thereby binding the silane linker to the inner surface of the microfluidic channel; and

b) reacting the capture ligand with the silane linker, thereby binding the capture ligand to the inner surface of the microfluidic channel.

119. The method of Claim 118, wherein the silane linker can be represented by the following structural formula:



wherein:

R_1, R_2 and R_3 are each, independently, -H, an alkyl, or an arylalkyl;

L is an alkylene, a cycloalkylene, a heteroalkylene, a heterocycloalkylene, a sugar residue, or an arylalkylene; and

X is an –NHR, -OH, -SH, a halo, wherein R is –H, an alkyl, an arylalkyl, or an aryl.

120. The method of Claim 118, wherein the capture ligand is selected from the group consisting of a nucleic acid, a single stranded DNA, a double stranded DNA, a protein nucleic acid (PNA), a protein, peptide, an antibody, an antibody fragment, an antigen, a lectin, a carbohydrate, and a sugar residue.

121. The method of Claim 108, wherein the step of functionalizing the interior of the microfluidic channel comprises polymerizing a gel in the interior of the microfluidic channel, wherein the gel comprises one or more capture ligand.

122. The method of Claim 121, wherein polymerization of the gel is initiated by radiation.

123. The method of Claim 121, wherein the capture ligand is selected from the group consisting of a nucleic acid, a single stranded DNA, a double stranded DNA, a protein nucleic acid (PNA), a protein, peptide, an antibody, an antibody fragment, an antigen, a lectin, a carbohydrate, and a sugar residue.

124. The method of Claim 108, wherein the polysilicon is removed from the trenches by etching with an aqueous solution of KOH.

125. The method of Claim 108, wherein the polysilicon layer is planarized via chemical-mechanical polishing

126. The method of Claim 108, wherein the first and the second silicon nitride layers are low-stress layers and are deposited using low-pressure chemical vapor deposition.

127. The method of Claim 126, wherein the first and the second silicon nitride layers have a thickness in the range of between about 100 nm and about 1200 nm.

128. A method of packaging a device comprising one or more suspended microfluidic channel formed in a semiconductor wafer, comprising the steps of:

a) patterning a substrate with one or more separately addressable electrodes, wherein the electrodes can be aligned with each microfluidic channel of the device;

b) preparing a poly(dimethyl siloxane) gasket having one or more fluid channels and one or more opening;

c) bonding the gasket to the substrate;

d) patterning a common electrode on the surface of the device, wherein the common electrode is formed on each microfluidic channel;

e) bonding the gasket to the device, wherein the fluid channels of the gasket connect with the inlets and outlets of the microfluidic channels of the device and each opening on the gasket is aligned with one or more suspended microfluidic channel.

129. The method of Claim 128, further comprising the step of forming one or more holes in the substrate connected to the fluid channels of the gasket.

130. The method of Claim 128, wherein the gasket is bonded to the substrate via plasma bonding.

131. The method of Claim 130, wherein the gasket is bonded to the device via plasma bonding.

132. The method of Claim 128, wherein the gasket has a thickness in the range of between about 10 μm and about 100 μm.

133. The method of Claim 128, wherein the microfluidic channels of the device have a depth in the range of between about 100 nm and about 3000 nm.

134. The method of Claim 133, wherein the walls of the microfluidic channel have a thickness in the range of between about 100 nm and about 1200 nm.

135. The method of Claim 134, wherein the fluid channels of the gasket have a depth of between about 10 μm and about 100 μm.

136. The method of Claim 128, wherein the common electrode and the separately addressable electrodes are made of a material that is, independently, selected from

the group consisting of gold, nickel, platinum, aluminum, copper, antimony, tin, indium, chromium, titanium, and alloys thereof.

137. The method of Claim 136, wherein both the common electrode and the separately addressable electrodes are made of gold.

138. The method of Claim 128, wherein the substrate is made of a material selected from the group consisting of a ceramic, glass, a plastic, a circuit board, and a silicon chip.

139. The method of Claim 138, wherein the substrate is glass.

140. A method of packaging a device comprising one or more suspended microfluidic channel formed in a semiconductor wafer, comprising the steps of:

a) forming one or more fluid channel and one or more cavities in a substrate, wherein the cavities can be aligned with the microfluidic channels;

b) patterning the cavities of the substrate with one or more separately addressable electrodes, thereby forming electrodes that can be aligned with each microfluidic channel of the device;

c) patterning a common electrode on the surface of the device, wherein the common electrode is formed on each microfluidic channel;

d) bonding the substrate to the device, wherein the fluid channels of the substrate connect with the inlets and outlets of the microfluidic channels of the device and each trench of the substrate is aligned with one or more suspended microfluidic channel.

141. The method of Claim 140, further comprising the step of forming one or more holes in the substrate that connect to the fluid channels of the substrate.

142. The method of Claim 140, further comprising the step of etching one or more openings in the semiconductor wafer that connect to the fluid channels of the substrate.

143. The method of Claim 140, wherein the substrate is made from a material selected from the group consisting of a ceramic, glass, a plastic, and a silicon chip.

144. The method of Claim 143, wherein the substrate is glass or a silicon chip and the fluid channels and one or more cavities are etched in the substrate.

145. The method of Claim 144, wherein the substrate is glass or a silicon chip and is anodically bonded to the device.

146. The method of Claim 140, wherein the microfluidic channels of the device have a depth of between about 100 nm and about 3000 nm.

147. The method of Claim 146, wherein the walls of the microfluidic channel have a thickness in the range of between about 100 nm and about 1200 nm.

148. The method of Claim 147, wherein the fluid channels of the substrate have a depth of between about 10 μm and about 100 μm.

149. The method of Claim 140, wherein the common electrode and the separately addressable electrodes are made of a material that is, independently, selected from the group consisting of gold, nickel, platinum, aluminum, copper, antimony, tin, indium, chromium, titanium, and alloys thereof.

150. The method of Claim 149, wherein both the common electrode and the separately addressable electrodes are made of gold.

151. A method of packaging a device comprising one or more suspended microfluidic channel formed in a semiconductor wafer, comprising the steps of:

a) patterning a surface of a substrate with one or more separately addressable electrodes;

b) forming a photoresist on the surface of the patterned substrate;

c) irradiating the photoresist through a mask, thereby removing the photoresist from predetermined areas of the substrate;

d) electroplating a metal in the area of the substrate where the photoresist was removed, thereby forming the walls of the one or more microfluidic channels and the walls of the one or more cavities;

e) removing the remainder of the photoresist;

f) patterning a common electrode on a surface of the device having an inlet and an out let for each of the microfluidic channels;

g) bonding the electroplated metal to the common electrode, wherein the fluid channels formed by the electroplated metal walls connect with the inlets and outlets of the microfluidic channels of the device and each cavity formed by the electroplated metal walls is aligned with one or more suspended microfluidic channel.

152. The method of Claim 151, further comprising the step of forming one or more holes in the substrate that connect to the fluid channels.

153. The method of Claim 151, further comprising the step of etching one or more openings in the semiconductor wafer that connect to the fluid channels.

154. The method of Claim 151, wherein the substrate is made from a material selected from the group consisting of a ceramic, glass, a plastic, and a silicon chip.

155. The method of Claim 154, wherein the substrate is glass.

156. The method of Claim 151, wherein the electroplated metal is soldered to the common electrode.

157. The method of Claim 156, wherein the soldering material used is tin, lead, gold, or alloys thereof.

158. The method of Claim 151, wherein the microfluidic channels of the device have a depth of between about 100 nm and about 3000 nm.

159. The method of Claim 158, wherein the walls of the microfluidic channel have a thickness in the range of between about 100 nm and about 1200 nm.

160. The method of Claim 151, wherein the fluid channels have a depth of between about 10 μm and about 100 μm.